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Atmospheric Measurement Techniques Discussions

Interactive comment on "GPS-PWV jumps before intense rain events" *by* Luiz F. Sapucci et al.

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Response latter for Referee 3

General comments from Referee#3

This manuscript presents an analysis of time series of PWV from a GPS station and of precipitation from a nearby X-band radar for a period of 56 days in Brazil. The characteristics of PWV variations before and after the peak in precipitation rate are described with wavelet analysis and more classical tools (Spearman correlation coefficient and histograms). The discussion is focused on the rapid variation of PWV preceding the

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peak in precipitation (increase followed by decrease). Though this feature is quite well known, both for the Amazon and for other regions of the world, the main novelty I see from this work is the fact that the increasing phase in PWV can be built upon successive pulses as suggested by Fig. 7. This subtle modulation of PWV was detected in this study thanks to the high temporal resolution of the PWV time series (1-minute). The potential for predicting the occurrence of intense precipitation with the help of real-time GPS PWV data is also suggested but not demonstrated. The topic of this study is interesting and might contribute to a better understanding of the moist processes involved in deep convection over land in the tropics (though such physical interpretation is beyond the scope of this paper). However, in its present form, this manuscript cannot be accepted for publication. A major rework of the data analysis and presentation is required. Major and specific comments are given below.

Response: Taking into count the comments, corrections and suggestions from the Reviser, the new version of the manuscript was significantly changed, particularly in the analysis of the results: discussion about the GPS-PWV jump occurrence before precipitation, wavelet, and derivative analysis. A new data processing of the time series had to be done to include 4 new figures in the text. We agree that these figures are very important for better discussing the results and to evidence some obtained results, which were not suitably emphasized in the previous version. The additional analyses improved substantially the scientific quality of the results. Thanks for these very interesting suggestions. About the specific items presented by Reviser, some aspects of this revision deserve some general comments to explain the changes done in the new version of manuscript. These general comments are presented here:

- (I) Data processing and interpretation of results:

- The relationship between GPS-PWV jump and PWV pulses was clarified in the new version of the manuscript and some inconsistencies were removed. The jump is com-

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posed by several pulses; the jump is evidenced in a scale that represents a time period of 32-64 minutes and the pulse is shorter and more variable.

- Some inconsistencies about the intensity and intensity/extension of the precipitation events were removed in several parts of the manuscript.

- The most important aspects associated to GPS data process, particularly those associated with ZTD estimates, were better detailed. Several information about the configuration adopted to use GOA-II software, such as information about the mapping function and Stochastic model for tropospheric delay (Random walk method) and its constrains were included.

- (II) Wavelet analysis:

- The wavelet analysis was revised and we included the wavelet correlations for different lags, which was very important to emphasize the lag of 30 minutes and show the relevance of interrelations between the time series in scales related to time periods smaller than 32 minutes where the PWV pulses are contained.

- We improved and reorganized considerably the introductory section about the wavelet, changing some notation to make the text easier to readers, excluding some technical information, including some synonymous, and explanation about the evaluation and choice of different wavelet mothers.

- Results of significance tests, such as the cone of influence, was included in the wavelet power Spectrum in the new version of manuscript.

- (III) Result analysis:

- Based on your specific comments about the GPS-PWV jump discussion, two new figures were organized and included in the manuscript. The Fig. 4 shows other GPS-PWV jumps observed before different extension rain events and in Fig. 5 the composite

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of time series was done in order to highlight the most prominent features of the PWV jumps, as suggested. This composite was normalized by maximum GPS-PWV values before maximum precipitation and we agree that this figure was very suitable to emphasize the jump occurrence and the time scale that it is more frequent.

- A histogram of the time lag between the maximum GPS-PWV and the time of the maximum rainfall is presented and clearly shows that there is a range of lag time between these two maximums. Certainly, the precipitation area and the temporal resolution of GPS-PWV here employed have an important impact on this lag time. For instance, Adams et al (2013) using rain gauge and PWV with sampling rate of 30 minutes found out lag zero, however, in this study, we show that there are PWV oscillation in higher frequency than 30 minutes, which can represent an area around GPS antenna and not only a punctual measurement.

- The GPS-PWV derivative time series before severe precipitation of the upper tercile was done and included in the manuscript, which allows the analysis of the occurrence of stronger PWV derivatives and associating them to PWV pulses.

- (IV) GPS-PWV potential for predicting the occurrence of precipitation

- The present study has the aim to show the GPS-PWV jump, to discuss the time variability, the jump as function of the rainfall intensity and discuss the possible associated physical mechanism. As the number of precipitation events used in this study is not suitable to show the skills of the model, we opted in not presenting the suggested short hindcast. Developing this model is a proposal for future article (in development), which should be involved a larger dataset with independent events to building and testing appropriately the model. Besides, the data processing used here are not in real time and there are some aspects that deserve attention in sensibility experiments (mentioned by revisers) such as: the size of the time-windows before severe precipitation, the constrains of temporal evolution of the ZTD estimation, precipitation area around the GPS

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antenna, and others.

Others minor corrections pointed by reviser, such as inconsistencies, use of not conventional scientific terminology, and technical corrections, were taken in count in the elaboration of the new version of the manuscript. Specific comments point-by-point are presented below. The numbers (in the new version of the manuscript) of the changed lines and respective page in each point are listed and highlighted in green. The numbers of figure in the response refer to 13 figures of the new version of the manuscript.

Specific comments

(I) Wavelet analysis:

1) **Referee#3:** The wavelet correlation method and results are not properly used and interpreted. Several times the authors interpret the period bands for which the wavelet correlation values are displayed as lag times (P2L29, P620, P6L29, P9L19). For example (P6L29): “an interrelation analysis can be performed with the WCC of GPS-PWV and precipitation time series to evaluate the correlation at different lags in time, scale by scale”. The results provided in figure 5 and 6 are correlation values for a range of time periods indicated in the x-axis and wrongly labelled “wavelet scale”. This kind of plot is typically given for a zero-lag (see e.g., Whitcher et al., 2000). Where are the wavelet correlations for different lags? The analysis could be complemented with wavelet cross-correlations as a function of lag for different scales such as in Whitcher et al., 2000. Proper use of wavelet cross-correlations for lead/lag analysis would probably not require using the classical Spearman correlation (Fig. 8).

P11L28-P11L32 Fig.10 Response: We agree that explore wavelet cross-correlations as a function of lag for different scales is useful for analysis of GPS-PWV jumps. We included the wavelet correlations for different lags complementing the graphics of the Fig 8 and 9. The wavelet cross-correlations (WCC) as a function of lag for different scales are presented in Fig 10. We corrected the x-label, where we preferred to keep the time periods instead of wavelet scales. We also improved the information in the Caption of Fig 8 and 9. The inconsistencies in the text were corrected.

2) **Referee#3:** The significance of wavelet spectra (Fig. 3 and 4) and correlations (Fig. 5 and 6) is not addressed, though mention to "significant" frequencies is made in several places in the text. Most tools used for wavelet analysis provide also results of significance tests or confidence intervals. These should be used to highlight objectively the significant frequencies.

Caption Fig. 6 Fig.7 Response: Unfortunately this information was missing, which was included in this new version of the manuscript. The cone of influence was included in the wavelet power spectrum of the Fig. 6 and 7. The error bars in Fig. 8 and 9 represents the confidence interval, which means if the zero is outside the interval, the WCC is statistically significant. Some information about the statistic significance of the results are presented in the text and in the caption of these figures.

3) **Referee#3:** It is not said what the error bars in Fig. 5 and 6 represent.

P9L31-P33 Fig. 8 Fig.9 Response: Information about the error bar were included in the Caption of this figure, as follows: "The 95% Confidence Interval for each WCC is estimated considering a Gaussian Distribution after applying the Fisher's Z Transformation (Whitcher et al 2000)".

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4) **Referee#3:** The description of wavelet analysis methodology in section 3 is not sound. Only fragmented information is given on the used methods, without justification of the choices (e.g. of mother wavelets, continuous vs. discrete wavelet transforms). On the other hand very highly-technical information is given (e.g. use of non-decimated discrete wavelet transform, use of pyramidal algorithm...) which won't be explicit to the general readers of AMT journal. So I recommend that this section explains a bit more about the general principles and choices that were made, and the implication of the choices that are made. For example, one might question about the robustness of the results regarding the choice of mother wavelets. For the more technical aspects, refer to the proper literature where appropriate.

P9L7-P33 Response: We improved and reorganized considerably the introductory section about the wavelet, changing some notation to make the text easier to readers of Whitcher et al(2000). We excluded some technical information and included the synonymous of non-decimated discrete wavelet transform (NDWT): Maximal Overlap DWT (MODWT) and, instead of Symlet we used the synonymous Least Asymmetric wavelet with the number of the filter length. We included briefly a comment about the evaluation and choice of different wavelet mothers. Some information about the choice of the discrete wavelets was discussed showing the evaluated wavelets, as well as which one was selected and the consequences of this choice.

(II) Analysis of data and interpretation of results

5) **Referee#3:** The GPS data processing options should be more detailed (see specific comments below). Some fundamental aspects are missing, such as the constraints of the stochastic model of the ZTD parameters. They impact directly the magnitude of variability in the retrieved PWV time series.

P5L1-L3 Table 1 Response: We agree that the most important aspects associated

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to GPS data process not had been presented suitably in the previous version of the manuscript, particularly those associated with ZTD estimates. The section "2.2 High temporal resolution GPS-PWV time series" was drastically changed with the inclusion of the several information in the configuration adopted to use GOA-II software, such as information about the mapping function, ZHD and ZWD values used *a priori*; Stochastic model for tropospheric delay (Random walk method) and its constrains. These information were organized in Table 1.

6) **Referee#3:** The dimensions of the area around the GPS station used to study the PWV-precipitation relationship is said to be a “key factor” (P5L5). In consequence, some preliminary tests should be presented which give insight into the sensitivity of results to this parameter. It is not clear how the representativeness (P5L11) is estimated.

P5L28-P6L7 Response: The rainfall area employed in this study is only a reference for the description of GPS-PWV jump. For instance, if a raingauge is employed to only an area of 20 cm radius is recorded and it is considered represents the rainfall from a large region. From another side, if the whole radar area is employed a rainfall over 100 km radius is recorded and could be associated to the GPS-PWV. In both cases representativeness and the lead time (for a nowcasting application) should be considered. In the raingauge case, rainfall will be underrepresented because only rainfall over the raingauge will be considered and for the radar case rainfall far from the GPS-PWV will be considered and cannot be associated to the local increase in PWV. The representativeness of the GPS measurement is still an open question because it depends on the vertical distribution of the water vapor and mainly from the combination of elevation angles of the GPS satellite and the elevation angle threshold employed in the PWV processing. Actually, the area employed was the one having the best correlation with PWV and nearly the expected representativeness of the GPS receiver for this location, but it is expected to vary as function of the region and satellite

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configuration. This information was included in the manuscript.

7) **Referee#3:** Fig. 7 shows one case of heavy precipitation where PWV shows a strong peak achieved in several steps (so-called “pulses” in the text and inconsistently labelled “jumps” in the Figure). This kind of analysis should be made for other cases to establish if the pulses are a robust feature of the heavy precipitation events. It is not clear if the authors associate the 32-64 min periodicities detected by the WCC with these pulses? It would also be interesting to add a composite of time series to highlight the most prominent features of the PWV jumps. The authors refer extensively to Adams et al. (2013) regarding a maximum of PWV 1-h before the maximum of precipitation. Inspecting this reference carefully reveals that on average the peak in PWV is rather coincident with the peak in precipitation (Fig. 2 in Adams et al., 2013) or slightly ahead (Fig. 3 and 4), in accordance with other results (e.g. Holloway and Neelin, 2010). The case illustrated in Fig. 7 shows indeed a lead time of 1 hour but about 50% of the cases show lead times between 0 and 30 min (Fig. 8). So the 1-h lead time should not be considered as a general rule.

P7L1-P8L24 Fig.4 Fig5 Response: The relationship between jump and pulse was clarified and the mentioned inconsistency (Fig.3) was removed. The jump is composed by several pulses and is better represented in the scale related to the time period of 32-64 minute. The pulse is shorter and more variable. This was included in the manuscript. The Fig. 3 present the indication of pulses and the PWV-GPS jump before the precipitation. Based on this comment, two new figures was included in the manuscript. The new Fig. 4 shows other GPS-PWV jumps observed before different extension rain events and in the Fig. 5 the composite of time series was done in order to highlight the most prominent features of the PWV jumps, as suggested. All the 18 events listed by Table 2 are taken into account in this analysis. The analysis of this results is presented to highlight the hardiness of the GPS-PWV jumps feature before

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heavy precipitation events. The results obtained to follow this suggestion was very interesting and improve significantly this section of the manuscript. The time lag between the maximum GPS-PWV and the time of the maximum rainfall is presented in a sub plot in Fig.5. It is important to highlight that the there are many precipitation events of lower intensity and extension in which the GPS-PWV jumps are not observed. In these cases, the maximum GPS-PWV is observed in the maximum precipitation, consequently, the time lag is zero (37% of the cases evaluated). In this histogram, it is clear there is a range of lag time between these two maximum. Certainly, the precipitation area and the temporal resolution of GPS-PWV here employed have an impact on this lag time. For instance, Adams et al (2013) using rain gauge and PWV with sampling rate of 30 minutes find out lag zero, however, in this study we show that the GPS-PWV signal can represent an area and not only a punctual measurement besides the GPS. This discussion was included in the manuscript after present the Fig. 5.

8) **Referee#3:** In section 4.1, show an example of correlation function to help explaining what is meant by the "positive and negative correlations" (in fact maximum positive/minimum negative correlations) and specify the time window of analysis (+/- 1 hour). Again, the histograms in Fig. 8 suggest that the case in Fig. 7 might be a specific case because the minimum correlation is probably reached for a lag time around 0. Illustrating other cases and providing composite plots would help to better catch the general situation. Moreover, Fig. 7 is a case where the pulses preceding the peak in PWV are outside of the correlation window. The link between the pulses and the peak in PWV and in precipitation should be investigated in more detail as this is to my opinion the real innovation of this work.

P7L22-L26 Fig.11 Response: The composite of PWV-GPS and precipitation time series and a new figure with other cases of jumps was included. The relation between the water pulses and GPS-PWV jumps was better discussed. The derivatives larger than 9 mm/h obtained from GPS-PWV in high temporal resolution were associated with

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this pulses, and these results were appropriately emphasised, following this comment. Based on your comment about the histogram correlation a mistake was identified and corrected. The minimum negative correlation in zero was not been taken in account, which was included and the problem corrected. The Fig.11 was updated. Thanks so much for that. In fact, the case showed in Fig.3 is the special case because it was one of the strongest events registered during the CHUVA Vale experiment, the lag time zero in the minimum negative correlation maybe a consequence of this intense precipitation. A similar result can be observed in Fig.4a, for the precipitation occurred during the 315 DoY. The title of figures of the Spearman correlation histograms were corrected, as suggested.

9) **Referee#3:** In section 4.2, the PWV derivatives are computed in a 1-hour window preceding the peak in precipitation. This window is too small, namely for the case of Fig. 7, as it does not include the part of time series with the pulses. Extend the time window to analyse this feature in more detail and also to not give too much weight to the decreasing phase after the peak in the statistics computed in Table 2. Some sensitivity tests should be made to choose the best window size.

P13L5-L7 Response: In this conceptual study, the size of the time-window used to analysis of the PWV derivatives was defined based on wavelet correlation results, which given the clear indication that PWV-GPS oscillation for the scale related to period band between 32 and 64 minutes are associated with precipitation events. The time window used here is 60 minutes. The histogram of the time lag between the maximum GPS-PWV and the time of the maximum rainfall presented in the new figure 5, suggest that this time-window is suitable for this data set. We agree that others time-windows should be tested in sensitivity experiment, particularly when a large data set be used to developing a nowcasting tool based on GPS-PWV values. In this future study probably this time window can be adaptive, which should be larger depend on intensity and frequency of the stronger PWV positive derivative (associated with water

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vapor pulses), as before precipitation events of the Fig. 3. The reasons about the size of the time-window used in this study were included in the manuscript.

10) **Referee#3:** I suggest to add also a figure with the time series of PWV derivatives for all 6 cases of the upper tercile (e.g. superposed on one graph showing also the average PWV derivative and precipitation).
P14L1-L5 Fig.13 Response: The suggested figure was done and included in the manuscript (new Fig. 13), which improved the analysis of GPS-PWV derivative before severe precipitation and allowed the analysis of the occurrence of the stronger PWV derivative and associating them to PWV pulses.

11) **Referee#3:** The sentence P2L29 announces a “study of correlation and lags with rainfall events to form a conceptual model with predictive capacity that can hence be used in developing a nowcasting tool for strong precipitation events”. However, section 4.3 doesn’t provide any proof of concept of this model. I suggest a short hindcast study is performed, based on the data from this campaign, to evaluate the skill of the proposed detection method.
P3L15 Response: The number of precipitation events used in this study are not suitable to show the skill of the model. This phrase was rewritten to avoid the false expectancy in the reader. The new phrase is "... capacity, which can be useful in nowcasting tool for strong precipitation events." Developing this model is a proposal for future article (in development), which involve a larger dataset with independent events to build and test the model. All precipitation events from several CHUVA campaigns is being explored. The studied model should be adjusted for different precipitation regime to obtain the acceptable skill. The present study has the aim to show the GPS-PWV jump, to discuss the time variability, the jump as function of the rainfall intensity and discuss the possible associated physical mechanism.

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12) **Referee#3:** Some interpretation is made about the underlying physical processes leading to the observed PWV jumps:

- (1) P8L25-29: “The presence of low-level water vapor convergence can be attributed to mechanisms such as gravity wave forcing (Raymond 1987) or other larger-scale forcing mechanisms. The increased water vapor convergence (i.e., positive PWV derivatives) may also simply be a reflection of the unstable surface parcels accelerating upwards, thereby vertically advecting a larger surface specific humidity to higher levels in the atmosphere without necessarily any larger-scale dynamical forcing”
- (2) P10L31: “This increase in the stronger negative derivative frequency before more intense events (upper and middle terciles) is associated with the conversion process from water vapor to liquid water. . .”
- (3) P11L5: ‘the processes responsible for the maintenance of precipitable water suspended in the atmosphere are very complex and highly nonlinear”
- (4) P11L8: “The increase in moisture convergence appears to be due to an increase in the frequency of convergence pulses.”

These assertions relate either to very general atmospheric processes or are highly speculative as recognized by the authors, P8L29, "Given the limitations of the observations, our interpretation of the physical mechanisms responsible for the jumps remains speculative." I suggest to remove sentences which cannot be supported by other studies of similar phenomena or provide the necessary proofs, e.g. by analysing additional data.

Response: We agree some of these sentences are speculative, but we also should open the discussion to possible physical effects related to this feature and at the same be precise. We changed the above sentences as:

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- (1) P8L5L7 The sequence of pulses of positive increases in the PWV could be a result of several physical processes. Some of the physical process that can explain these pulses could be low-level water vapor convergence forced by gravity wave (Raymond 1987) or simply unstable surface parcels accelerating upwards... P8L22L24 To understand what the physical mechanisms responsible for these pulses are a specific field campaigns design are needed.
- (2) P13L22L24 One possible reason for this increase in the stronger negative derivative frequency before more intense events (upper and middle terciles) is the conversion process from water vapor to liquid water.
- (3) P14L8-L9 Therefore the use of only a maximum threshold from a GPS-PWV derivative, as suggested by Iwabuchi et al. (2006), is not sufficient to predict intense rainfall , several atmosphere processes are very complex and highly non-linear.
- (4) P14L11 was deleted.

(III) Inappropriate and vague terminology

13) **Referee#3:** The PWV jumps which are the main topic of this work (as advertised in the title) are defined inconsistently in several places in the manuscript: P2L28 (“sharp increase in PWV”), P8L22 (a “pattern” of maximal PWV), P9L14 (“oscillations”), and Fig. 7 (pulses defined P8L25 are labelled “jumps”). Please be consistent.
P7L3-L8 P12L6 P15L3-L7 Fig.3 Response: The appointed inconsistency was removed. The definition used in Abstract and introduction using the term "sharp increase" was used in the section 3 (replacing "pattern") and conclusion (replacing "oscillation")

to describing correctly the GPS-PWV jump. The sentence mentioned, which the term "oscillation (jumps)" appear is not a definition. It was rewritten to maintain the consistency. The Fig. 3 the mistake about the label "jumps" instead of "pulses" was corrected, as well suggested. A label "GPS-PWV jump" was included in this figure.

14) **Referee#3:** Precipitation intensity is measured as the 95th percentile of all precipitation data in the area (P5L22). However, later, precipitation fractions are referred to as precipitation intensity (Table 1 and 2). Intensity terciles are referred to in section 4.2 and 5. Please be consistent.

P1L18-L20 P7L16 and many others Table 2 3 Response: The reviser is right, some inconsistencies about the intensity and intensity/extension of the precipitation events were present in several part of the previous version of the manuscript, which were removed. The term "precipitation intensity" is used for analysis of 95% percentiles of precipitation time series. The term "precipitation intesity/extension" is used for analysis of rain fraction above different thresholds of precipitation, for example wavelet cross correlation analysis. The term "precipitation extension" is used for analysis of percentage of precipitation above of one specific selected thresholds, for example: precipitation extension terciles explored in the derivative analysis (table 2 and table 3), which are defined in function of the precipitation fractions above 35 mm h^{-1}.

15) **Referee#3:** It is not clear if the precipitation fractions are computed from the 95th percentile of precipitation or from all data and grid points?

P6L21 Response: The precipitation fraction are computed as the fraction of the area of 4.4 km per 4.4 km around the GPS antenna with precipitation rates above some chosen threshold. This phrase was rewritten in the manuscript.

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16) **Referee#3:** Expressions such as “expressive”, “expressive changes”, “evident”, “more evident” are not adequate. Please use conventional scientific terminology.

Response: As also suggested by reviser 1, all occurrences for the terms "expressive" were replaced by other more suitable (see Specific comment 11-Referee#1). The term evident were removed from manuscript using the following word (underline):

P10L27 "... these cases makes the result discussed for Fig. 6 more understandable"

P12L14 "...the correlation between the GPS-PWV and precipitation time series is more higher."

P13L20 "Notably, this effect is observed for the middle and uppe..."

P15L11 "...which is more stronger for events of large intensity and extension."

17) **Referee#3:** What is a positive oscillation? (P8L18, P12L3...) or a positive increase?

P15L3 Response: The term "predominantly positive" was excluded of phrase in the section 4 to avoid the inconsistency pointed by reviser. In conclusion section the phrase was rewritten associating with PWV derivatives, which are predominantly positive before intense precipitation.

Technical corrections

18) **Referee#3:** P4L7: specify which “possible noise sources” are taken into account and how.

P4L23-L25 Response: This phrase was rewritten in the new structure of this section and the term "possible noise sources" was excluded because is impossible eliminate the "possible noise sources" in the geophysics process. We would like to highlight in this phase that in the GPS data processing used to generate PWV time series with high temporal resolution is necessary to taking into consideration several known uncertainty

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Discussion paper

sources in order to minimize them. This phrase was rewritten in new structure of this section, which this rigorous data-processing was demonstrated with details through the items listed and suggested by reviser in his specific comment (5-Referee#3).

19) **Referee#3:** I understand that you used the regional model for Tm of Sapucci 2014. So it is not the Bevis 1992 relationship that is used (P4L13). Please correct.

P5L5-L9 Response: The methodology used to converting ZTD into PWV is from Bevis et al (1992), but the TM values were calculated using the regional model suggested by Sapucci (2014). This was clarified in the manuscript.

20) **Referee#3:** This Tm model requires RH. It is not said what RH data are used to compute Tm.

P5L5-L9 Response: The TM model suggested by Sapucci (2014) for CHUVA-Vale region (Subtropical ocean) are not requires RH values. Only temperature and pressure values are required in this case. The RH values are required in other region such as subtropical continent, South and Northeast (Sapucci, 2014).

21) **Referee#3:** P4L17: "3.1% of data are missing in 2 days". This represents about 1.7 days for the total period of 56 days. I suggest that you completely remove these 2 days from the analysis because the spline interpolation won't give correct results.

P5L12-L14 Response: In fact, these period were removed from analysis results. The results from spline interpolation were used only in wavelet analysis, which require time series without failures. The phrase was rewritten in the manuscript.

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22) **Referee#3:** It is important to specify the tropospheric model used in the GPS data processing: is it a random walk? Are both ZWD and gradients estimated? What are the constraints of temporal evolution of these two parameters? Did you make some tests with different constraints? (the analysis of 6-min time differences in section 4.2 might be strongly impacted if the constraints parameters are too small or too big).

P5L1-L3 P14L18-L20 Table 1 Response: In the new section 2.2 the information about the stochastic model used in the data processing were presented, as well as information about azimuthal gradient estimated. The constrains of temporal evolution of these parameters used were the default value suggested by JPL: 8.333E-8 (km per square-root second) and 8.333E-9 (km per square-root second), respectively. We agree that this values might impact the variability of the PWV estimates in high frequency, and others values should be tested ahead in this research. This information was included in the manuscript.

23) **Referee#3:** P6L8-10 and in many other places, results from Adams et al., 2013, should be rather described in the introduction.

P3L11-L13 Response: Adams at al. 2013 in this paragraph and other places were moved to introduction section, which was better described, as also suggested by reviser 1 (9-Referee#1) and reviser 2 (16-Referee#2).

24) **Referee#3:** P7L17: what do you mean by “amplification”?

P10L25 Response: The Fig. 7 is a aggrandizement or enlargement of the FIg.6 in short specific period. The term was replaced by "enlargement" in the new version of manuscript.

25) **Referee#3:** P7L31: why is quasi-symmetry (“a good property for the mother wavelet”) important to this study?

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P11L5 Response: One important advantage of the quasi-symmetry is related to the reconstruction. As this is not the case for this paper, this information was omitted.

26) **Referee#3:** P8L19:20: “maximum peak” replace with “maximum”
P7L7 Response: Replaced as suggested.

27) **Referee#3:** P10L12: “the lowest threshold” complete with “among the 3 that were tested”.
P13L8 Response: Completed as suggested.

28) **Referee#3:** P10L16: what are rainfall events with periods without precipitation?
P13L11-L13 Response: In the statistic analysis from GPS-PWV derivative besides the three threshold of precipitation intensity, the derivative histogram was calculated for the other rainfall events with precipitation intensities smaller than 20 mm h-1 and periods without precipitation. This histogram is called by "other cases" in Figure 9. This is better described in the new version of manuscript.

29) **Referee#3:** P11L11-19: description of results from Fig. 9 should go to section 4.2
P13L30-P14L1 Response: The partial analysis of Fig. 12 presented in the section 4.3 was moved to section 4.2, as suggested.

30) **Referee#3:** P11L21-25: results from past studies about nowcasting should go to the introduction. Note that these references can probably be updated.
P14L22-L30 Response: In this study the PWV estimates used are post processed and

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the following question naturally appear: Are PWV estimates in real time able to capture the jumps before the precipitation observed? These previous studies shows that the quality of PWV obtained in real time is similar the post-processed, which are mentioned in this context. These references was updated with the inclusion of the results reported by Shi et al (2015) (doi: 10.1109/TGRS.2014.2377041).

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Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2016-378/amt-2016-378-AC2-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-378, 2016.